A proposal for

METALLIC VAPOR LAMP RESEARCH

Prepared for
Commander
Naval Air Systems Command
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Washington, D.C. 20360
Attention: Mr. Webster K. Whiting

EOS Proposal P075-41-46D 1 April 1967

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CONTENTS

SECTION 1

INTRODUCTION

Electro-Optical Systems, Inc. (EOS) is pleased to submit this proposal for research on cesium plasma devices. The EOS organization has acquired an extensive background in advanced materials technology and radiation physics as related to physical electronic and arc discharge devices, and is particularly well qualified to contribute to this research program. In addition, EOS has shown an outstanding capability in modulator power supply design and fabrication for lasers, arc discharge lamps, traveling wave tubes, and other physical electron devices.

The proposed six-month program includes a high-power pulser design as well as complete parametric measurements of the cesium plasma.

SECTION 2

PROGRAM PLAN

EOS suggests that the proposed program consist of two distinct technical phases. During Phase I the minimum radiation decay time of cesium in the lower and upper IR wavelength ranges will be obtained as rapidly as possible. Phase II will consist of a much more comprehensive study of the limiting plasma parameters to very high-power (approximately several hundred kW) pulsing and short microsecond radiation decay times.

2.1 PHASE I — CESIUM SPECTRAL MEASUREMENTS

There are two distinct wavelength regions of interest in the radiation emanating from cesium plasmas. The furtherest infrared band will be considered first, that is, the upper IR band. This band consists mainly of line spectra; therefore the radiation is made up of primarily bound-bound transitions. This being the case, the radiation in this band will follow the current waveform identically. Thus, microsecond radiation decay times depend only on the ability to obtain microsecond turn-off times for the current pulsing circuit.

To accurately determine the radiation mechanisms in the arc plasma, measurement of the spectral line intensities will yield the electron temperature in the plasma. Consider the spectral intensity relationship

$$I_{u\ell} = \frac{n_o}{V} g_u A_{u\ell} h\nu_{u\ell} \exp(-E_u/kT) \qquad (1)$$

where $I_{u\ell}$ is the spectral line intensity of the radiation transition between levels u and ℓ in an atomic system; n_o is the number of atoms per unit volume in the ground state; V is the internal partition function of the neutral radiating atom; g_u is the atomic weighting factor for level u; $A_{u\ell}$ is the Einstein probability for spontaneous emission from the initial state u to the final state ℓ; h is Planck's constant; $\nu_{u\ell}$ is the emitted frequency of radiation; E_u is the energy of level u measured from the ground state; and T is the electron excitation temperature associated with the radiating atoms. Therefore, if

$$\log\left(\frac{I_{u\ell}\,\lambda_{u\ell}}{g_u\,A_{u\ell}}\right)$$

is plotted versus E_u, for the various spectral lines in the band of interest, the slope of the line will correspond to the average vapor electron temperature. In addition, measurement of the pressure broadened widths of these lines will provide density determinations.

The second band of interest is the lower IR band. This band consists entirely of continuum radiation; that is, the radiation appears to be made up of free-bound (recombination) and free-free (Bremsstrahlung) transitions. This offers a much more complex radiation decay process. It is the main purpose of this phase to determine the type of process and the radiation decay times involved.

The major experimental approach will be to operate a Have Cable type lamp at some low dc level and, by standard pulse forming techniques, pulse the lamp to a high current level. At the plateau of the pulse, the lamp will be crowbarred in less than ten microseconds and the radiation decay time measured (a more comprehensive discussion of pulses considerations is given in Subsection 2.3). This procedure will be followed at various vapor pressures and currents to obtain decay times as functions of these parameters. Pressure will be varied by using an oven to control the thermal environment of the lamp to the desired temperature for a particular vapor pressure up to a maximum of 1000 torr. Current will be variable from 100A to more than 1000A. By varying the parameters, the onset of Bremsstrahlung will be determined.

All measurements will include spectral distribution measurements; that is, the arc plasma will be mapped to determine the variation of plasma radiation processes over the arc volume.

In summary, the major purpose of Phase I is to determine the applicability of the Have Cable lamp to fast radiation decay times (on the order of a microsecond) with approximately 40 kW input which correspond to approximately 2 kW of radiation in the lower IR band of interest.

It should be pointed out that Phase I may indicate that the present Have Cable configuration does not lend itself to plasma conditions conducive to Bremsstrahlung and therefore fast microsecond radiation decay times. Thus the purpose of Phase II will be to determine the performance limits of these types of plasma devices and to define the performance conditions for high-power, fast-decay pulsing.

2.2 PHASE II — PULSED CESIUM PLASMA INVESTIGATION

This phase of the program is intended to: (1) provide the performance conditions for high-power, fast-decay time pulsing, (2) to determine the maximum constraints on lamp design for pulsed operation, (3) to define the optimum system using the device which incorporates these conditions.

Special plasma test vehicles will be designed for this phase which will allow parametric determination of the effects of envelope diameters, interelectrode spacing and cathode size. All of these dimensional factors can effect the pressures at which the onset of Bremsstrahlung is observed as well as the plasma stability of high-current pulses. Envelope dimensions effect compression wave formation as well as acoustical resonance frequencies. The above mentioned considerations will all have an influence on the devices ability to respond to high frequency pulsing up to 4000 hertz. All radiation decay times will be evaluated on the basis of whether high frequency operation would be possible. Interelectrode spacing relates to plasma densities as well as plasma voltage effecting the energetics of the particle interactions. As the cathode size decreases, reducing emission density, electron energies are increased correspondingly. Thus, all of these geometrical factors are capable of influencing the generation of Bremsstrahlung radiation through alteration of electron energies.

Using a pulser capable of high power output and variable pulse width and pulse height, plasma radiation characteristics will be studied over a wide range of variables. These variables will include vapor pressure, pulse electrical current, pulse power, pulsewidth, wavelength and position within the arc (Subsection 2.3 provides a more thorough discussion of the pulses.)

It is very important to cover this wide range of parameters since the existence of Bremsstrahlung radiation is strongly dependent on achieving high electron density and electron temperature. In an arc plasma, electron density is controlled by the degree of ionization; thus, it is desirable to create the highest degree of ionization possible. To develop insight into the problem, consider the I-V characteristics of a cesium plasma. If voltage is plotted on the ordinate and current along the abscissa the I-V characteristic first exhibits a negative slope. Moving toward increasing current, the negative slope flattens and becomes a zero slope and then at higher current develops a positive slope. The break for the negative slope occurs at about 10 to 15A for pressures nominally in the 100 to 1000 torr range. It is unknown at what current the slope becomes positive but it is definitely in excess of 500A. Bremsstrahlung should be observed as the pulse currents reach the positive slope region. This is based on the assumption that the increasing plasma voltage at the high currents will produce considerably more ionization and/or higher electron temperatures due to the higher electron energy gain per mean free path. As pressure is varied, the breaks in the slope of the I-V characteristic also varies, thus altering the onset of Bremsstrahlung. Variation of pulsewidth yields information on the formative lag time within the plasma. That is, the generation of the current pulse is delayed a specific time after the applied voltage pulse due to plasma mobility and space charge neutralization considerations. Since the electron density controls the magnitude of free-free transitions, pulsewidth should have an observable effect on the radiation processes in the arc plasma.

2.3 PULSES AND MODULATOR CONSIDERATIONS

The primary purpose of this portion of the program is to support IR lamp research and testing. Of particular interest in Phase I of this program is the development of a pulser capable of turning the lamp off in approximately 1-microsecond. Phase II will be concerned with the feasibility investigation and development of a laboratory modulator capable of driving the lamp at 1 to 4 kHz repetition rates, duty cycles to 5%, and electrical pulse decay rates of approximately 1-microsecond.

2.3.1 PHASE I

The primary goal of the electronics for this phase of the program will be to investigate microsecond turn-off of the lamp. To implement this requirement an existing EOS modulator will be modified to provide microsecond shutoff times on a one shot basis. This modulator will be capable of pulsing the lamp above 1000A and turning at off in approximately 1 microsecond. This portion of the program will provide not only data concerned with lamp radiation but will also provide preliminary lamp I-V data of importance to the Phase II modulator design.

This approach has been chosen over using capacitor discharges, and spark gaps or thyratron devices for two reasons. First, the modulator proposed above is available and was developed for use with the particular lamp under consideration and can readily be modified as indicated. Secondly, the voltage and impedance levels associated with thyratrons, ignitrons and spark gaps are not compatable with the lamp voltage and impedance levels. The lamp voltage will be approximately 100 to 300V at an impedance of approximately 0.1 ohms. The problems associated with these devices are explained in the following section concerning Phase II. This phase of the program includes a thorough study of these devices and their associated problems.

Secondly a commutating silicon controlled rectifier modulator will be built in breadboard fashion. Some of the new developments in SCR devices indicate it is feasible to build this type of device with shutoff times in the 10 microsecond region. Although this device will not provide data at 1 microsecond shutoff times, it will provide a repetitive system as opposed to the one shot system mentioned above. This system will be used to obtain lamp impedance and pulsed radiation data over a range of pulsewidths, pulse heights, and lamp pressures. It is expected that this modulator will be capable of driving the lamp to the 5000A level and above.

2.3.2 PHASE II

This portion of the program will consist primarily of an investigation of techniques for turning off the lamp in microsecond times at power levels to 300 kW (5000 to 10,000A) and at repetition rates to 4 kHz. Duty cycles to 5% will be considered.

Techniques are readily available for developing pulses of this nature in radar type systems. However, the impedance levels that are typically encountered in this latter application are in the range of 50 ohms and above as opposed to lamp impedances of 0.1 ohms. It is readily apparent that if a transformer with a turn ratio in the range of 10 or 20 to one can be developed with proper capacities and inductance, standard devices and techniques can be used. If such a transformer is not feasible new techniques and devices must be used. EOS proposes to investigate both areas of development. Pulse transformer designs and fabrication techniques will be thoroughly investigated. It is readily apparent that with the high levels of di/dt expected (5000 to 10,000A/μsec) and the relatively high turns ratio (20:1) that the design of such a transformer will be difficult if not impractical. EOS will, as part of the investigation, generate several transformer designs; the most promising of these will be fabricated for thorough study and investigation. The fabrication of special high-power pulse transformers is done within EOS in its transformer development section.

A simultaneous study will be conducted to develop a modulator that does not require the above coupling transformer. A thorough survey will be made of switching devices available as in development. Of particular interest is the silicon controlled rectifier. Although this device cannot at present be turned off in less than approximately 10 microseconds, it does show promise for the future. It is also possible that new methods of utilizing these devices may present a solution to the basic problem. These devices are attractive because when in the conducting state their impedance is 10 milliohms or less as opposed to thyratrons, spark gaps, etc., which have impedances exceeding the lamp impedance itself. A second problem occurs in that most of these devices require 5000V or more to switch in the required manner; these voltages are much higher than the 100 to 300V required by the lamp.

If after initial investigation in the above areas it appears that a complete solution to the problem cannot be found in the time scale of this program, a one shot type of modulator will be fabricated for testing lamps in the 5000 to 10,000A range. This device coupled with the SCR modulator of Phase I will provide the desired data. It is felt that the above program approach will result in a modulator breadboard that will be capable of testing the lamp in desired manner.

SECTION 3

PROPOSED STATEMENT OF WORK

EOS will conduct a six-month research program to include, but not be limited to the following items.

3.1 PHASE I CESIUM SPECTRAL MEASUREMENTS

3.1.1 EOS will fabricate a sufficient number of Have Cable type configuration lamps to measure radiation decay times, electron temperatures, and spectral linewidths in the wavelength regions of interest.

3.1.2 EOS will design and fabricate a single pulse crowbar supply to deliver short microsecond current decay times for the measures of item 3.1.1.

3.1.3 The range of parameters to be considered as goals by this phase will be:

Cesium Pressure: Up to 1000 torr
Pulse Currents: 100A to more than 1000A

3.2 PHASE II PULSED CESIUM PLASMA INVESTIGATION

3.2.1 EOS will design and fabricate cesium plasma test vehicles and perform experiments to determine the limiting conditions for high-power bremsstrahlung radiation.

3.2.2 EOS will design and fabricate a pulser capable of high power and short microsecond current pulse off-times with variable pulsewidth for the experiments of Subsection 3.2.1.

3.2.3 The range of parameters to be considered as goals by this phase will be:

Cesium Pressure:	Up to at least 1000 torr
Pulse Powers:	1 to greater than 300 kW
Pulsewidths:	10^{-6} to 10^{-3} seconds

3.3 REPORTS

EOS will deliver one semi-final report discussing the results of Phase I on or before 30 June 1967. EOS will deliver one final report 30 days after the completion of the technical effort.

SECTION 4

PROGRAM ORGANIZATION

4.1 MANAGEMENT

EOS has continued to strive for leadership in the area of advanced physical and gaseous electronic device research and development. Work related to this technical area is performed within several research divisions of the company. In particular, ultrahigh-temperature material research and gaseous electron device activities are centered in the Electro-Optical and Solid State Technology Division. The laboratories of this division are staffed by a highly qualified group of scientists, engineers, and technicians, most of whom have had extensive experience with high-temperature materials, vacuum and gaseous tube technology, and spectrographic measurements. As may be seen from the organization chart shown in Fig. 4-1, the proposed program will be organized under the project supervisor within the Light Source Engineering Section.

At EOS, the project supervisor is delegated a large measure of authority and responsibility for technical and administrative management, and is the focal point for all actions which affect contractual commitments and customer satisfaction. Assisting the project supervisor and monitoring his performance are the department manager and the division manager, both of whom will be closely associated with the daily activities on the project. When additional project support is required, this relationship assures full immediate responsiveness from other groups with the division. The division manager reports to the Technical Director and the Vice President of Research and Engineering. The Operations Manager of Research and Engineering and his staff formally

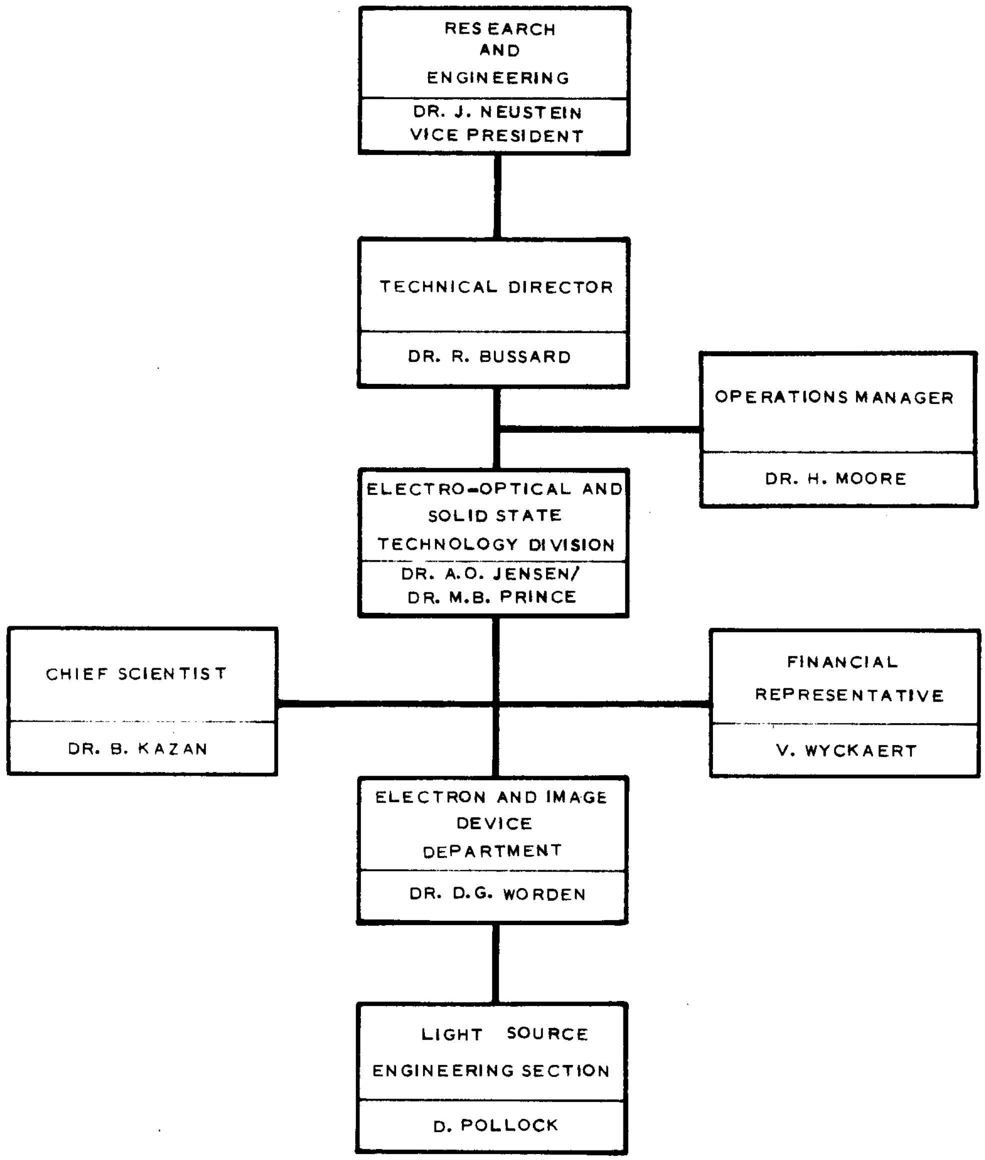

Figure 4-1. Program Organization

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review all aspects of each project on a monthly basis, thus assuring visibility of all problem areas and prompt corrective action. At EOS, these management functions are performed by scientists and engineers long experienced in solving technical problems. This provides additional responsiveness to the needs of each project and of each customer.

EOS is capable of performing all of the proposed tasks with its existing technical staff. EOS believes this team of integrated technical capabilities will provide the combination of engineering and applied research talent necessary to realize the objectives of the program. Internal management tools used for program control include:

a. Weekly contract cost reports from accounting data to analyze labor, materials, and purchase orders
b. Weekly project reviews with the department manager and division manager
c. Monthly project review with corporate management

Monthly technical and cost projection reports will be prepared for the customer's technical monitor, and periodic meetings will be held to review the program status and coordinate major decisions.

4.2 PRINCIPAL CONTRIBUTORS

Mr. D. H. Pollock, Manager of the Light Source Engineering Section will assume project supervisor responsibility for the program. In this capacity, he will be responsible for all program details. He will receive assistance from the manager of Electron and Image Device Department, the division manager, and the division financial representative.

4.3 PROGRAM SCHEDULE

It is suggested the program be divided into two separate phases which will start concurrently. Figures 4-2 and 4-3 show the proposed program schedules. Phase I will be 3-month program and Phase II will run for 6 months. An interim report will be issued at the conclusion of Phase I; final report covering all aspects of the program will be submitted within one month from the conclusion of Phase II.

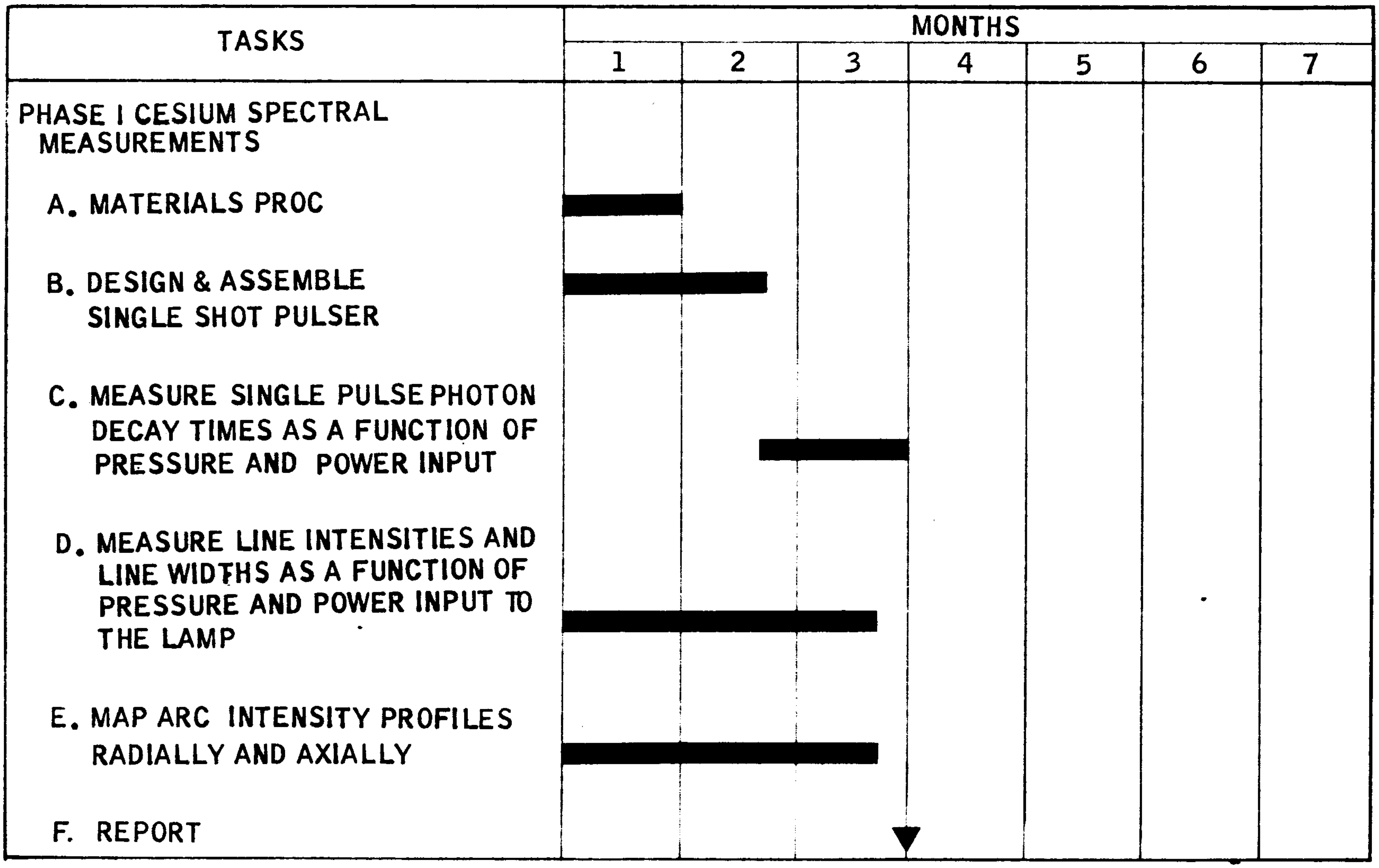

Figure 4-2. Phase I Cesium Spectral Measurements

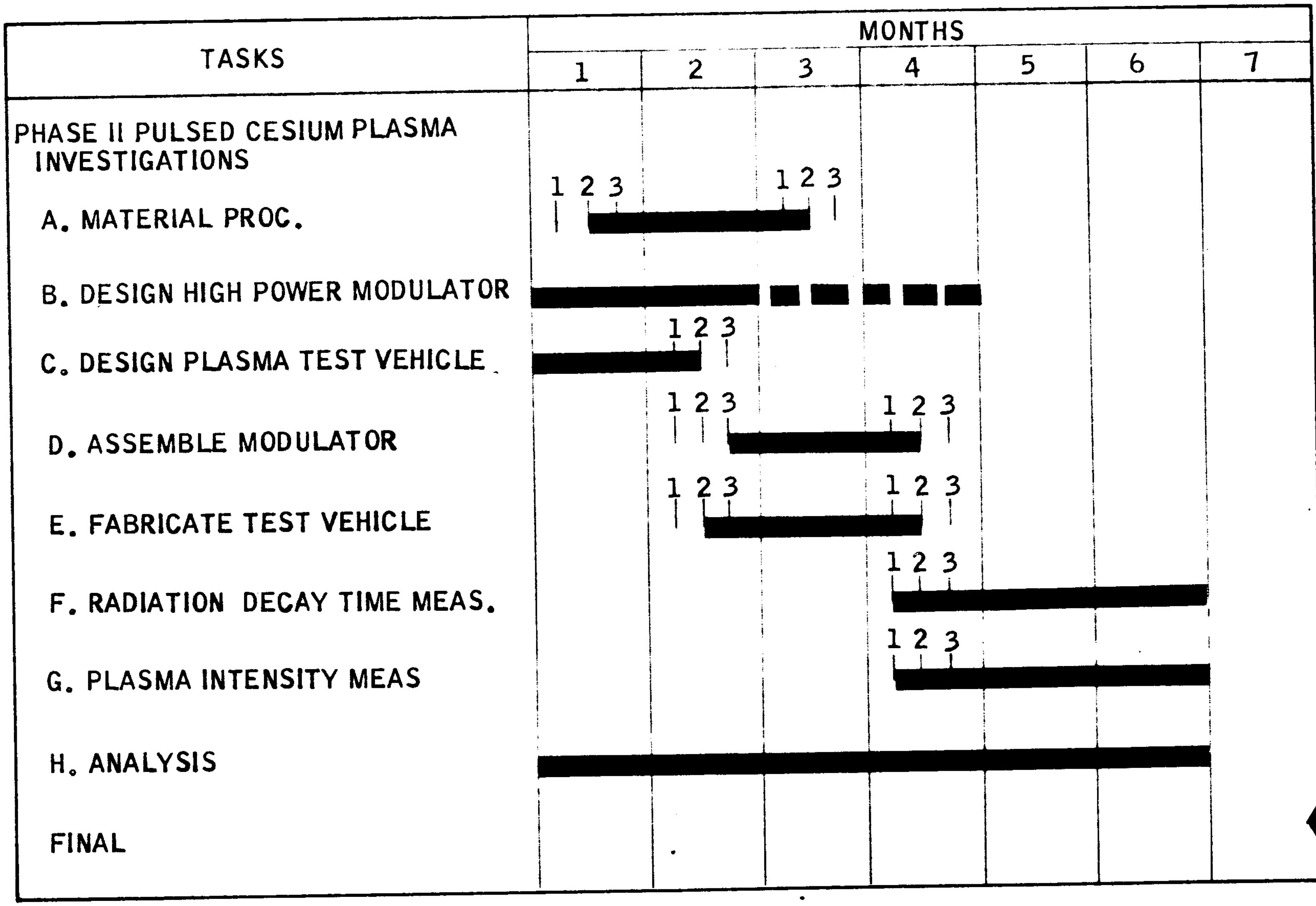

Figure -5. Phase II Pulsed Cesium Plasma Investigation

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SECTION 5

CAPABILITIES, FACILITIES, AND RELATED EXPERIENCE

5.1 CORPORATE FACILITIES

The operations divisions of Electro-Optical Systems, Inc., presently occupy more than 225,000 square feet of office, laboratory, and shop space in Pasadena, California. An ultramodern building, located at 300 North Halstead Street, provides 150,000 square feet of space and houses the Corporate headquarters and principal research laboratories. This structure is illustrated in Fig. 5-1 and has been occupied since November, 1962.

Among the facilities owned and operated by EOS is one of the most complete environmental laboratories to be found in the Los Angeles area. The laboratory is equipped with the latest environmental test equipment, such as an M.B. vibration system; a Tenney temperature, humidity, and altitude chamber; a Turbomachine shock unit; a Genisco centrifuge; and several EOS-designed high-vacuum chambers.

In addition, complete fabrication and test facilities, including all usual types of electrical and electronic test equipment, are available.

Other EOS facilities include a dust-free, temperature- and humidity-controlled laboratory for thin-film and special assembly work, metallographic equipment for preparation and analysis of materials, x-ray diffraction apparatus, a coating facility, noise-measuring facilities, infrared measurement equipment, and numerous other facilities that may be used as necessary to perform the proposed work.

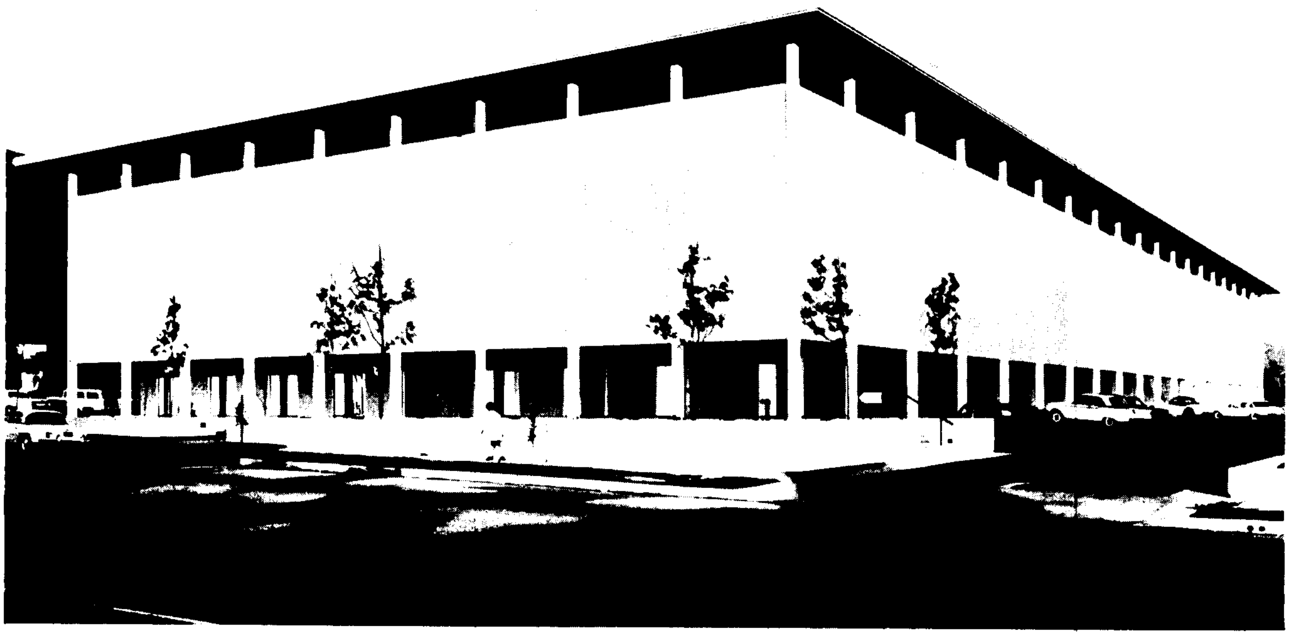

FIG. 5-1 EOS CORPORATE HEADQUARTERS

Because of recent and project growth, EOS has found it necessary to expand its present facilities. It is anticipated that work on the research and development complex shown conceptually in Fig. 5-2 will be completed in early 1968. This building program will consolidate, improve, and enlarge the existing facilities and will provide additional specialized laboratory and manufacturing areas for future programs.

5.2 ELECTRON AND IMAGE DEVICE DEPARTMENT FACILITIES

The Electron and Image Device Department of the Electro-Optical and Solid State Technology Division is presently utilizing approximately 8000 square feet of laboratory space, with another 2000 square feet available for expansion. At present, these facilities are devoted to high-temperature materials studies, tube and light source research, thermionic converter research and development, solid-state research and development, and prototype manufacturing. Under the direct cognizance of this group is a clean refractory metal machine shop, a heliarc-welding area, a complete plasma-spray facility, extensive RF vacuum brazing stations, a hydrogen brazing station, a helium leak detector, a cleanroom assembly area, a chemical cleaning area, multiple vacuum test stations complete with electron bombardment heaters, optical pyrometers, temperature instrumentation and controls, a Perkin-Elmer 112 recording spectrophotometer capable of scanning from 0.3 to 10 microns. This device is equipped with InSb liquid nitrogen cooled detectors for fast time response oscilloscope readout. In addition an American Instrument Company grating spectrophotometer capable of scanning from 0.2 to 1.5 microns is available in the department.

5.3 SPECTROMETRIC INSTRUMENTATION FACILITIES

Many of the contract programs presently being performed by EOS require the use of instrumentation for spectroscopic analysis of gas discharges

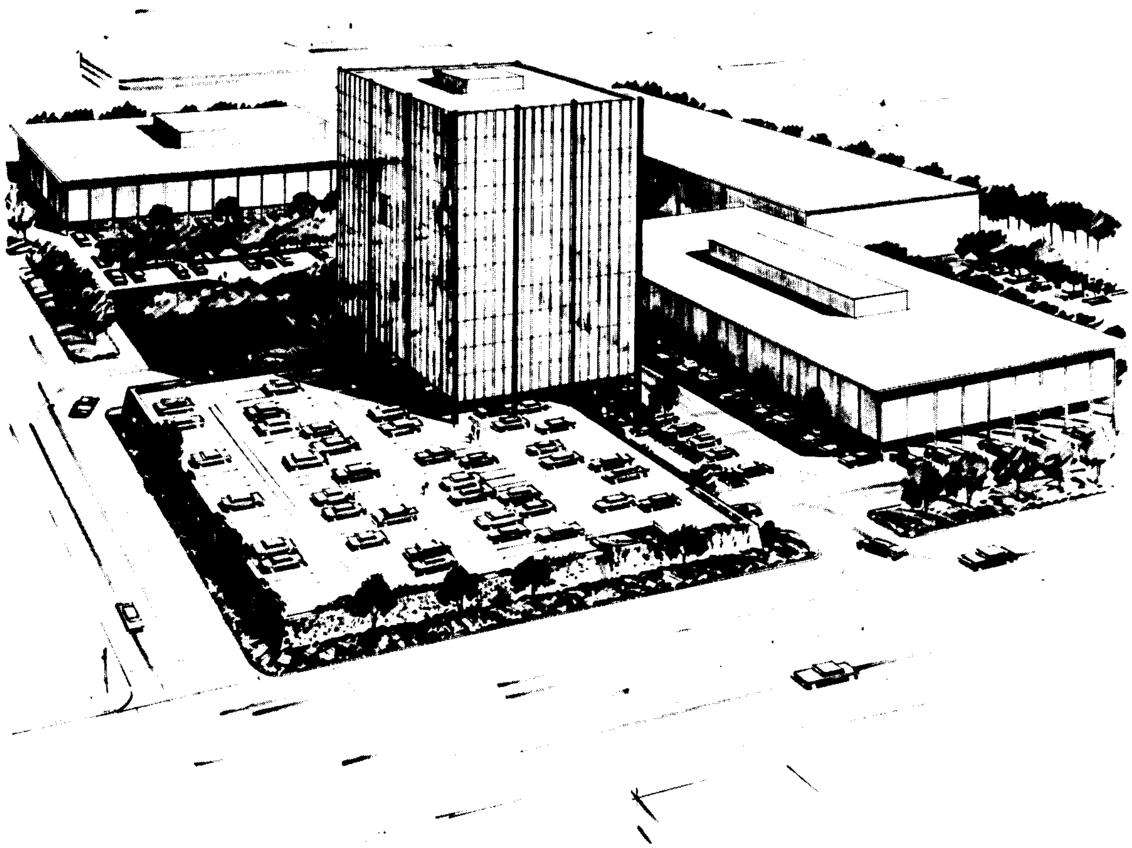

FIG. 5-2 EOS AEROSPACE SCIENCES AND ENGINEERING CENTER

and arc-type plasmas. The personnel available for the proposed program are well versed in the use of this instrumentation. The major items of spectrometric instrumentation are briefly described below.

Figure 5-3 shows a general view of one of the instrumentation laboratories. In the left foreground is a Jarrell-Ash 1.0 meter Ebert vacuum spectrometer (model 78-420) with its related electronic control and readout system. This high-resolution scanning instrument has good photoelectric speed and is commonly employed in the determination of plasma temperatures and species density.

In the background of Fig. 5-3, a Jarrell-Ash 0.75-meter high-aperture (f/6.3) spectrograph (Model 75-000) is being adjusted. This photographic instrument is ideal for recording spectra from weak sources and for many general analytical purposes where the highest resolution is not required. The photographic plates from this and the other spectrographs in use at EOS can be processed in either of two specially designed darkrooms.

The remaining instrument to be noted, in the right foreground of Fig. 5-3, is a Jarrell-Ash recording comparator microphotometer (Model 23-050). This instrument is used to reduce the data from the photographic spectrograms recorded on the 0.75-meter spectrograph or on the 3.4-meter spectrograph shown in Fig. 5-4. The latter instrument is a Jarrell-Ash 3.4-meter Ebert spectrograph (Model 70-320). This instrument was recently installed by EOS for high-resolution spectroscopic studies.

In addition, EOS facilities include a Perkin-Elmer 13U spectrophotometer which is capable of making reflection, transmission, and absorption measurements in the spectral range from 1900Å to 15.5 microns. Two interchangable prisms are used; one of fused silica and the other of sodium chloride. Its versatility lies in its extreme wavelength range

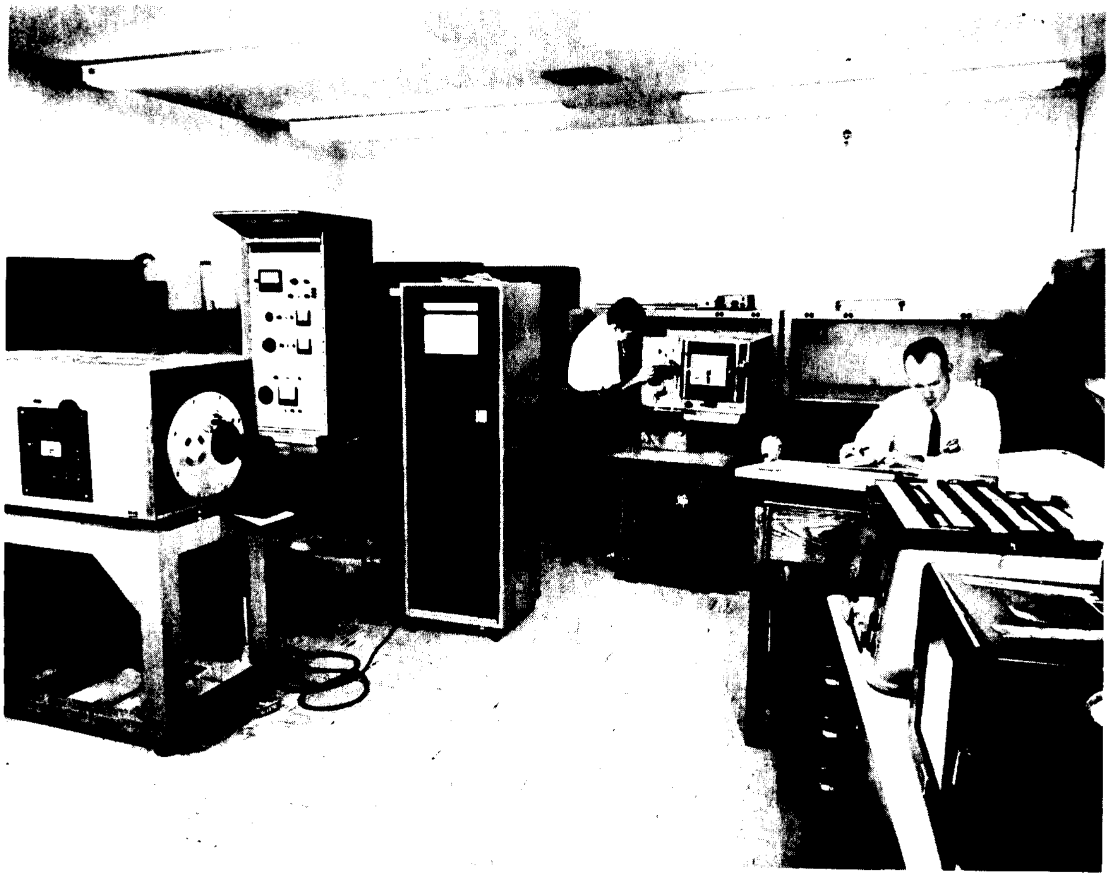

FIG. 5-3 SPECTROSCOPIC ANALYSIS LABORATORY

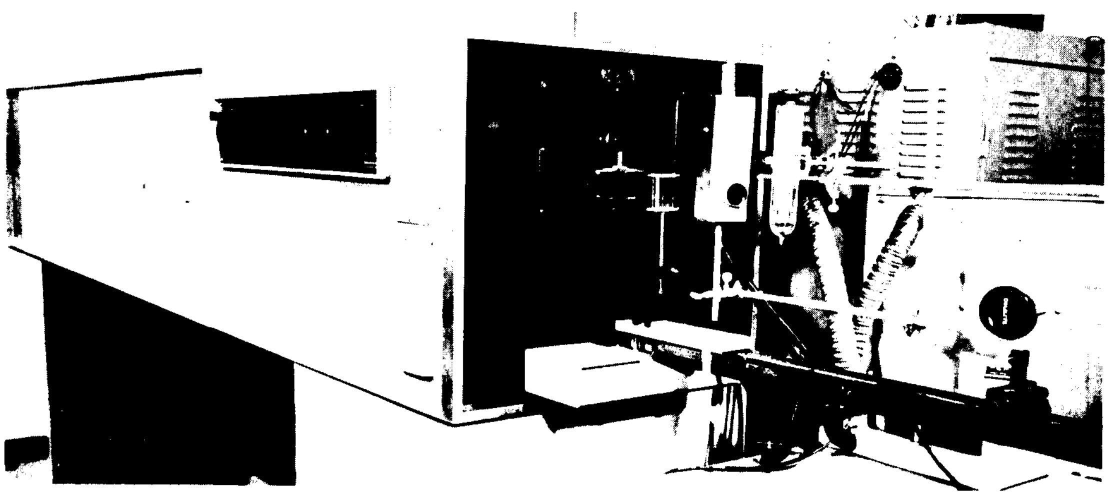

FIG. 5-4 3.4 METER SPECTROSCOPE

and its "building block" construction. The modules are interchangable, and each may be used independently of the others. A permanent record of measurements is provided by a strip-chart recorder.

5.4 ADDITIONAL FACILITIES

The facilities discussed in the preceding paragraphs are supplemented by the EOS Instrument Calibration Laboratory, a complete refractory metal machine shop, an electron-beam welding facility and a complete glass-blowing shop which includes a 12-inch glass lathe and several annealing ovens. This integrated capability has proved its effectiveness on past programs and is immediately available for the proposed program.

Electro-Optical Systems management will guarantee the availability of all equipment and facilities as scheduled for the proposed program. No phase of the program will be allowed to degrade in schedule or performance because of equipment or facility unavailability.

Some of the special facilities and equipments described above are illustrated in Figs. 5-5 through 5-12.

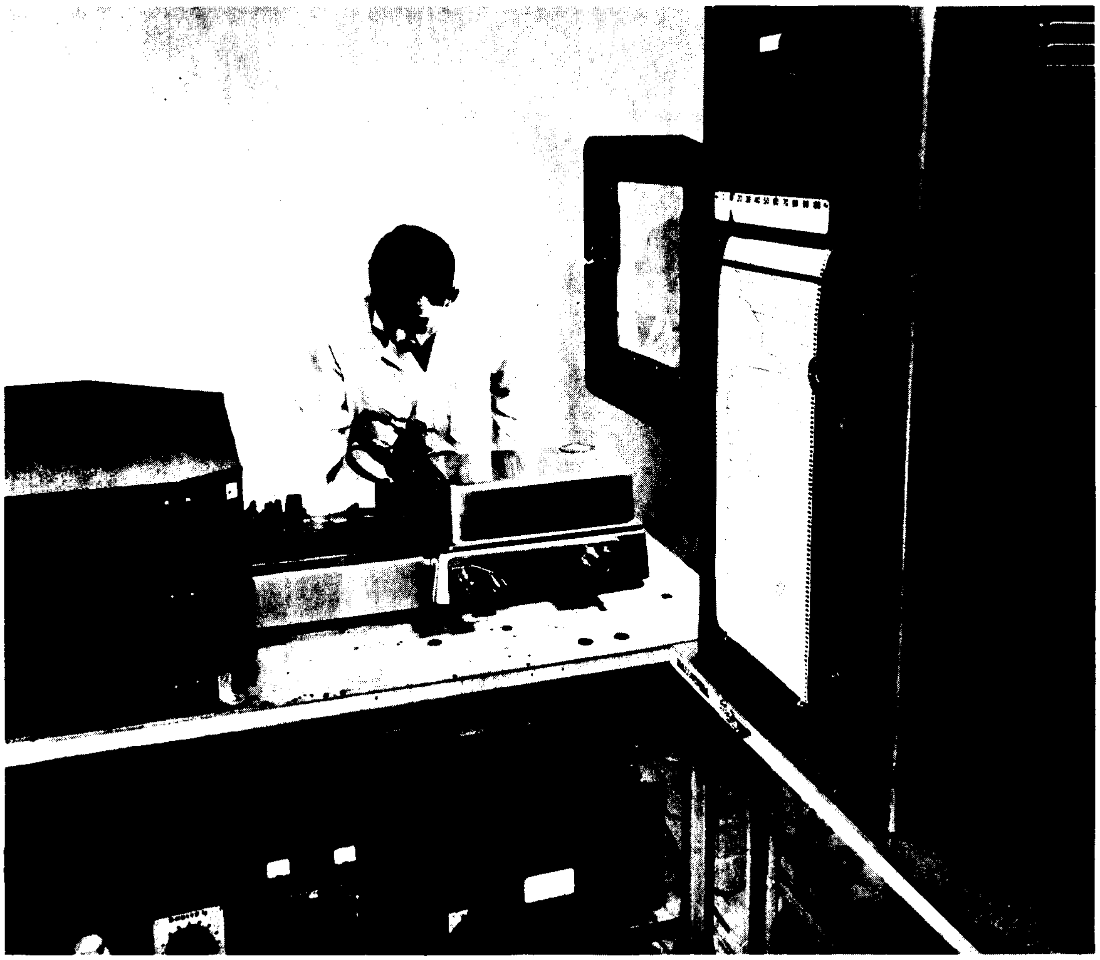

FIG. 5-5 PERKIN-ELMER MODEL 112 SPECTROMETER

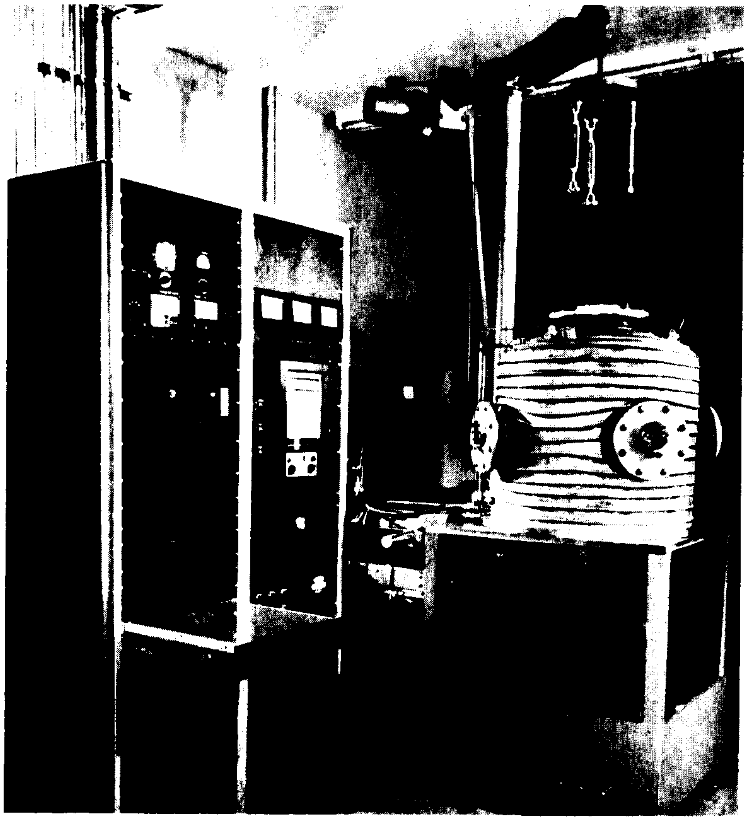

FIG. 5-6 HIGH-TEMPERATURE VACUUM FURNACE

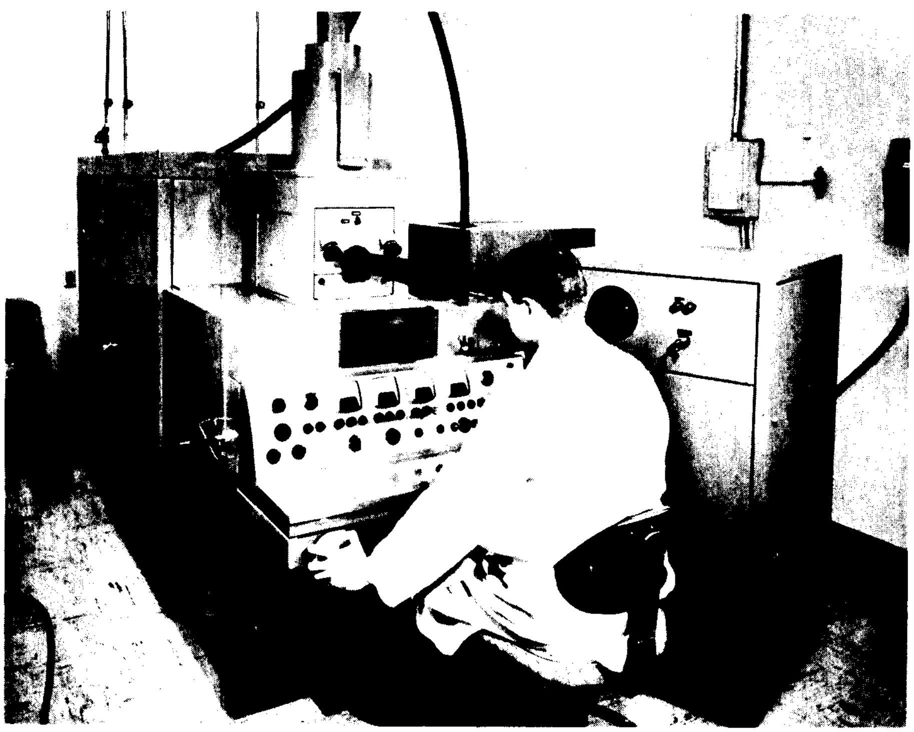

FIG. 5-7 ELECTRON BEAM WELDING EQUIPMENT

FIG. 5-8 MONTHLY CALIBRATION OF MICRO-OPTICAL PYROMETER WITH NBS REFERENCE LAMP

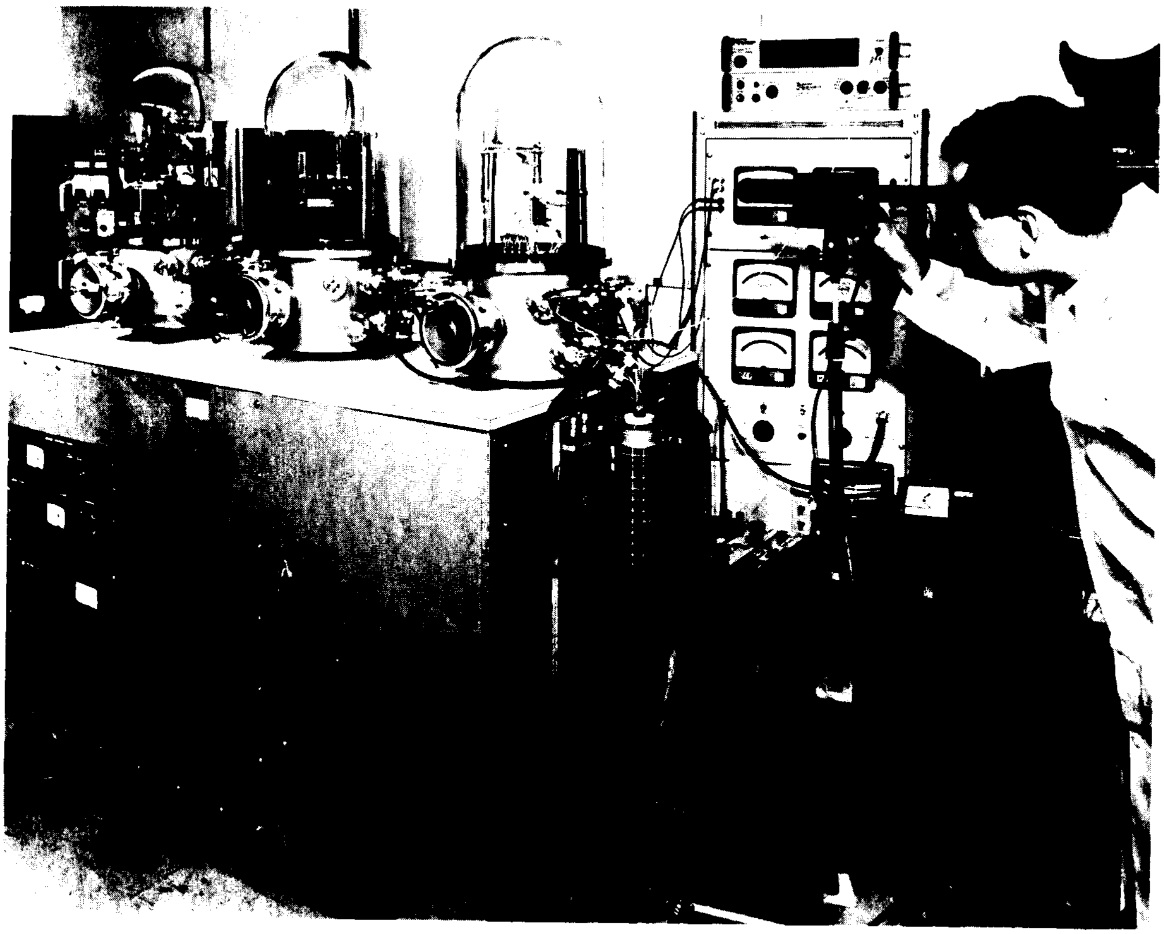

FIG. 5-9 VAC-ION PUMPED TEST CHAMBERS FOR ELECTRICAL VACUUM TESTING OF THERMIONIC CONVERTERS AND ELECTRON DEVICES

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FIG. 5-10 HIGH-TEMPERATURE BRAZE OF METAL CERAMIC SUBASSEMBLY

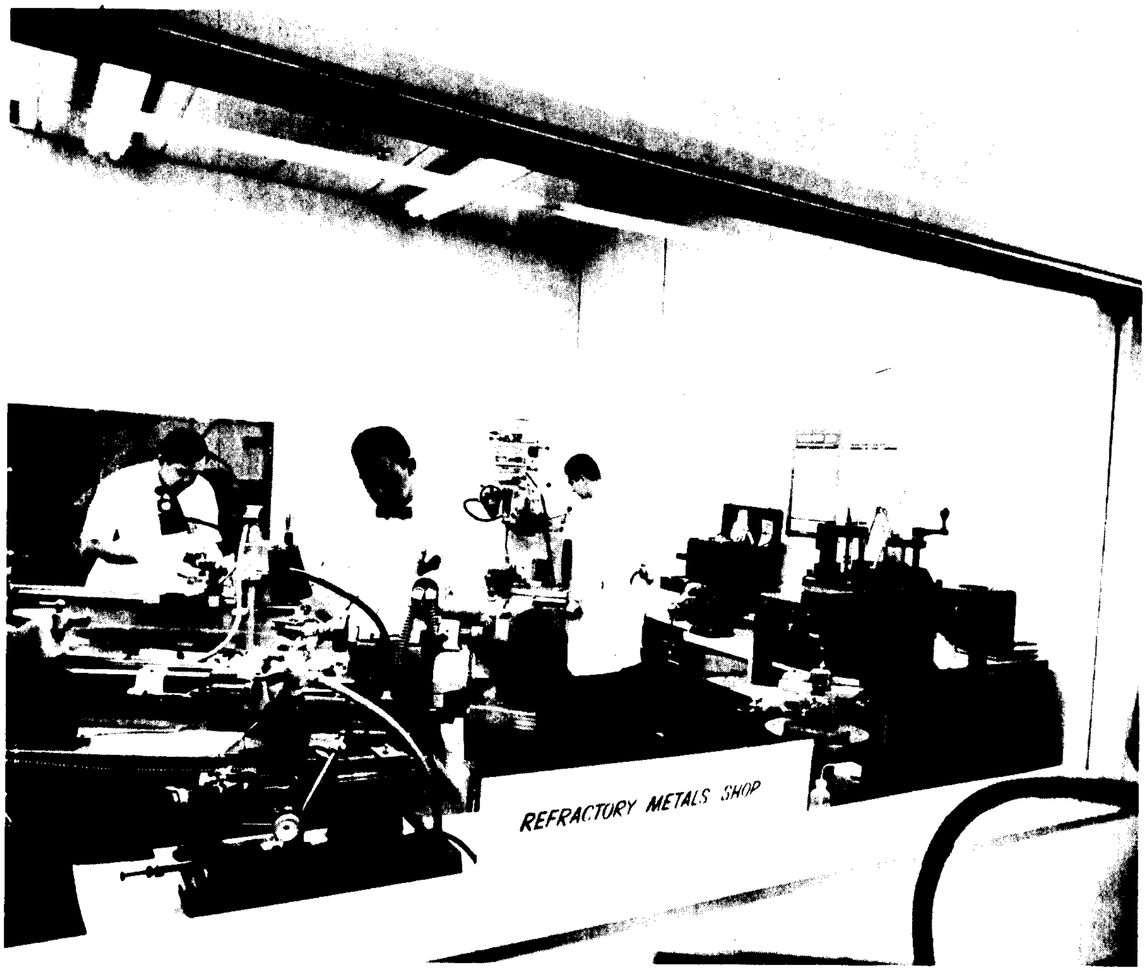

FIG. 5-11 REFRACTORY METAL MACHINE SHOP

FIG. 5-12 GENERAL MACHINE SHOP